Backgrounder

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Nanotechnology and National Security: Small Changes, Big Impact

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Nanotechnology is an emerging transformational technology that promises wide and dual-use applications in many fields, particularly national security. The United States is the world's acknowledged leader in nanoscience, but stiff international competition is narrowing America's lead. Many other countries, specifically European nations and China, have large, established nanotechnology initiatives. Most commercial applications of nanotechnology are still nascent.

In the near term, the most promising developments for national security will likely come from government research rather than from the application of commercial off-the-shelf nanotechnologies. To meet national security needs in the near term, the U.S. government needs to adopt new legislative and policy innovations, including promoting long-term research, distributing federal grants more widely, and promoting scientific travel and exchanges to maintain a supply of skilled experts. Over the long term, the government should remove capital and regulatory barriers to lower the cost of research and emerging technologies and should address safety and environmental issues.

What Is Nanotechnology?

"Nanotechnology" is derived from "nano," the Greek word for dwarf. It involves manipulating and manufacturing particles at the microscopic and even atomic levels, between 1 nanometer and 100 nanometers. By comparison, a human hair is roughly 100,000 nanometers wide.

Talking Points

- Nanotechnology is an emerging transformational technology that promises wide and dual-use applications in many fields, particularly in national security.
- The United States is the world's acknowledged leader in nanoscience, but intense international competition is narrowing America's lead.
- Congress and the Administration have done much to promote the development of nanoscience. The challenge is to maintain this momentum by facilitating commercial innovation and the application of new advances for national security purposes.
- To facilitate U.S. development of nanotechnology, Congress should continue to provide strong funding support for nanoscience research for national security purposes, reform visa issuance and management, and establish clear legal guidelines for responsibility and liability in nanotechnology research and development.

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Combining the ability to manipulate molecular structures with advances in genomics and other biological sciences has created a wealth of new research opportunities. By putting these unique properties to work, scientists are developing highly beneficial dual-use products in medicine, electronics, and many other industries that will also provide enormous defense and homeland security capabilities.

These scientific developments are creating new industries. The market opportunities are so substantial that many government and business leaders describe nanotechnology as "the next industrial revolution."

Nanotechnology was incorporated into manufactured goods worth more than $30 billion in 2005, and this figure is projected to reach $2.6 trillion by 2015.[1] However, since nanotechnology is relatively new, government research is critical for developing applications of this new technology, particularly in the field of national security.

A Small Beginning

The birth of nanotechnology can be traced to 1981, when Gerd Binning and Heinrich Rohrer, scientists at IBM Research, Zurich, created the scanning tunneling microscope (STM). The STM was the first instrument capable of performing operations at the atomic scale, such as adding or removing individual electrons to or from atoms and molecules. It gave researchers the unprecedented ability to change materials "from the bottom up." The two scientists won the Nobel Prize in physics for their invention in 1986.[2]

Within a few years, scientists had demonstrated the capability to manufacture nanoparticles. The discovery of fullerines (isomers or molecules of pure carbon that can be manipulated into unique structures, such as "buckyballs") in 1985 and carbon nanotubes (manufactured one-atom-thick sheets of carbon rolled into cylinders) in 1991 sparked further interest in nanotechnology.

These molecules have novel properties that make them potentially useful in a wide variety of applications, including electronics, optics, and other fields of material science. They also exhibit extraordinary strength and unique electrical properties. Carbon nanotubes are 100 times stronger than steel at one-sixth the weight, while buckyballs are hollow, making them well-suited for use as carriers of drugs or other materials.[3]

Nanotechnology Today

Current commercial nanotechnological products are limited to first-generation passive applications, such as nanoparticles, coatings, catalysts, and nanocomposites (materials formed from organic and inorganic components at the nanoscale). Products include cosmetics, automobile parts, clothing, and sports equipment. Research is quickly leading nanotechnology to converge with other fields, including biotechnology, information technology, and cognitive science.

Using techniques commonly found in semiconductor manufacture, researchers have created adjustable "quantum dots" by making "wells" and "corrals" on silicon chips where individual electrons can be trapped and held. The shell of electrons around every atom determines its properties, such as color and electrical conductivity. By filling these quantum corrals with differing numbers of electrons, researchers can create artificial "atoms" that have the same properties as any element on—or beyond—the periodic table, although these "atoms" are temporary and lack nuclei.

Simply adding or subtracting electrons from these wells changes the type of "atom." Grids of quantum corrals built across the surface of a silicon semiconductor chip would allow the creation of artificial molecules, which would theoretically allow the entire chip to have—at least on its surface—the physical properties of almost any material imaginable.

1. Sean Murdock, prepared statement in hearing, *Nanotechnology: Where Does the U.S. Stand?* Subcommittee on Research, Committee on Science, U.S. House of Representatives, 109th Cong., 1st Sess., June 29, 2005, p. 41, at *http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_house_hearings&docid=f:21950.wais.pdf* (September 13, 2007).
2. John W. Cross, "Scanning Probe Microscopy (SPM)," June 13, 2003, at *www.mobot.org/jwcross/spm* (May 10, 2007).
3. Nanotechnology Now, "Nanotubes and Buckyballs," March 14, 2006, at *www.nanotech-now.com/nanotube-buckyball-sites.htm* (February 26, 2007).

Some aspects of current nanotechnology also blur the line with biotechnology. For example, nanoparticles (clusters of tens to hundreds of individual atoms) have been used in medical research to fight diseases, including cancer. Researchers are also exploring ways to manipulate the genetic code that have tremendous implications in the diagnosis and treatment of diseases. A nanoparticle that encapsulates medication with biomolecules could be designed to bind only to the cells that need the medicine. Such research could also affect other disease research and possibly change the medical response to national catastrophic disaster.[4]

Nanophotonics is another growing field of nanotechnology research. Photonics, which uses light, is the ability to control photons for the purpose of carrying, processing, storing, or displaying information. Well-known applications of photonics include fiberoptic cable, television screens, computer displays, and laser and imaging systems.

In nanophotonics, scientists control the morphology of materials and, as a result, can now change how a material refracts light. Thus, nanophotonics is not simply the scaling-down of existing systems, but utilizing physics, functionalities, and design strategies that are different from regular photonics to produce tiny waveguides, microscopes on a single chip, better optical communications equipment, and chemical and biological sensors.[5]

National Security Implications

In 2000, the federal government established the National Nanotechnology Initiative (NNI) to promote nanotechnology research at the federal level. The NNI is managed by the Nanoscale Science Engineering and Technology Subcommittee of the National Science and Technology Council, an interagency organization of 26 federal agencies that coordinates planning, budgeting, and program implementation among defense and national security stakeholders. This structure is vital to disseminating information and fostering cross-disciplinary networks and partnerships. Both the Department of Defense (DOD) and Department of Homeland Security (DHS) are NNI members.

In addition to funding research, federal support through the NNI provides crucial funds for the creation of nanotech support infrastructure, such as nanoscale research labs, and for educational resources to develop a skilled workforce capable of advancing nanotechnology. These programs encourage business, including small business, to pursue nanotechnology opportunities.[6]

Military Applications. All branches of the U.S. military are currently conducting nanotechnology research, including the Defense Advanced Research Projects Agency (DARPA), Office of Naval Research (ONR), Army Research Office (ARO), and Air Force Office of Scientific Research (AFOSR). The Air Force is heavily involved in research of composite materials.[7] Among other projects, the Navy Research Laboratory's Institute for Nanoscience has studied quantum dots for application in nanophotonics and identifying biological materials.[8] In May 2003, the Army and the Massachusetts Institute of Technology opened the Institute for Soldier Nanotechnologies, a joint research collaboration to develop technologies to protect soldiers better.[9]

Nanotechnology has numerous military applications. The most obvious are in materials science. Carbon nanotubes and diamond films and fibers have higher strength-to-weight ratios than steel,

4. Press release, "Gold Nanorods May Make Safer Cancer Treatment," Georgia Institute of Technology, March 14, 2006, at *www.gatech.edu/news-room/release.php?id=889* (February 26, 2007).
5. Ravi Athale, "Implications of Nanophotonics Technology for National Security," video recording, presentation at The Heritage Foundation, March 29, 2006, *at http://multimedia.heritage.org/content/wm/Lehrman-032906.wvx* (February 26, 2007).
6. National Nanotechnology Initiative, "About NNI," at *www.nano.gov/html/about/home_about.html* (August 6, 2007).
7. U.S. Naval Research Laboratory, "DOD Laboratories," at *www.nanosra.nrl.navy.mil/laboratories.php* (February 26, 2007).
8. U.S. Naval Research Laboratory, Institute of Nanoscience, "Publications," at *www.nrl.navy.mil/nanoscience/publications.html* (September 12, 2007).
9. Curt Biberdorf, "Institute for Soldier Nanotechnologies Opens," Army News Service, May 28, 2003, at *www.globalsecurity.org/military/library/news/2003/05/mil-030528-usa02.htm* (February 26, 2007).

which allows for lighter and stronger armor and parts for vehicles, equipment, and aircraft. Such upgraded military Humvees would better protect soldiers from improvised explosive devices (IEDs) and small-arms fire.

In another application, adding nickel nanostrands (ropes of material no wider than a few molecules), which can conduct electricity, could make aircraft more resistant to lightning strikes. The nickel strands also have magnetic properties that may prove useful in filters and energy storage devices.[10]

The U.S. Army is actively pursuing nanotechnology for use in soldiers' uniforms, equipment, and armor. As part of the planned Objective Force Warrior Soldier Ensemble, the Army hopes to create a uniform that provides flexible armor protection for soldiers' limbs through the use of shear thickening liquids that solidify when force is applied to them. This would greatly reduce the weight that a soldier must carry. (Current body armor weighs around 25 pounds.)

Other features of the planned uniform include medical sensors, medical treatment capabilities, communications, and individual environmental control for the soldier and integrated thermal, chemical, and biological sensing systems woven into the garment's fabric.[11]

Nanotechnology would allow for more precise control of fuel combustion and detonation of explosives. Explosives and propellants could be constructed atom by atom to optimal particle sizes and ratios of ingredients so that the materials approach their theoretical limits of energy release. This would lead to smaller, more powerful rockets, propellants, warheads, bombs, and other explosive devices.

For slower release of energy, nanotechnology would allow for more powerful batteries, fuel cells, photovoltaic panels, and perhaps even more exotic methods of generating electrical power. Researchers at the Georgia Institute of Technology recently developed piezoelectric fibers, which someday may be used in fabrics that generate their own electricity, completely eliminating the need for batteries.[12]

In electronics, nanotechnology would allow the creation of ever-smaller computers and sensors, leading to integrated packages that could sense, discriminate, decide, report information, and provide control input to other devices. For example, tires that sense the surface over which they are traveling could automatically adjust tire pressure to maintain optimal traction.

Smart sensors could be used in single-chip chemical and biological agent laboratories that would be smaller, faster, and more accurate than current testing methods. They could also be attached to miniature disposable sensor platforms, allowing monitoring of a large battlespace at minimal cost, effort, and danger to soldiers.

In the more distant future, combining nanocomputers, sensors, and nanomechanical architectures into one system would make possible autonomously targeted and guided projectiles, such as bullets and rockets. Nanotechnology could also improve communications and information processing, whether on the battlefield or with the Oval Office, through microscopic computers, switches, lasers, mirrors, detectors, and other optical and electrical devices.

The laws of physics and optics change fundamentally at the near-atomic level. Instead of being masked by the manipulation of particles on the surface, materials can be changed at the optical electronic level. Materials that display one optical or electronic property at the macro level may display a different property at the nanometer level. Remarkable mechanisms become possible, such as negatively refractive optics that bend light at angles and in directions otherwise impossible.[13] Such devices could lead to the development of lenses that focus

10. U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate, "Nickel Nanostrands Expand Nanotechnology Engineering Capabilities," at *www.ml.afrl.af.mil/stories/MLB/asc_03_1622.html* (February 26, 2007).

11. GlobalSecurity.org, "Objective Force Warrior," at *www.globalsecurity.org/military/systems/ground/ofw.htm* (February 26, 2007).

12. American Association for the Advancement of Science, "Nanogenerators May Spark Miniature Machines," *EurekAlert!* April 13, 2006, at *www.eurekalert.org/pub_releases/2006-04/nsf-nms041306.php* (February 26, 2007).

almost instantaneously and light-bending camouflage that changes as the solider or vehicle moves.

One theoretical and exotic use of nanophotonic materials would be fiberoptic waveguides that actually strengthen the light beams passing through them. These could be used for long-distance, strategic-level communications systems or high-power narrow-beam lasers. With nanophotonics, optical computing, data storage, and signal processing become possible.

If the Defense Department is to remain a leader in exploiting nanotechnology, the Pentagon must ensure that it adequately understands how nanotechnology could be exploited for U.S. security and competitive advantage.

Homeland Security Applications. Only 0.25 percent of the government's 2004 funding for nanotechnology goes to the Department of Homeland Security. This is inadequate given that nanotechnology could play a major role in advancing the DHS capabilities. Nanomaterials could be used to create highly sensitive sensors capable of detecting hazardous materials in the air. For example, carbon-based nanotubes are relatively inexpensive and consume minimal power.

Other areas of nanotechnology pertinent to homeland security are emergency responder devices. Lightweight communications systems that require almost no power and have a large contact radius would give rescuers more flexibility. Nanotech robots could be used to disarm bombs and save trapped victims, reducing the risks to rescue workers.

Enlisting the Private Sector

In the United States, the commercial nanoscience industry is composed of traditional industrial sectors, newly formed startups, *Fortune* 500 companies, and academic research institutions. These groups will play a significant role in future developments of nanotechnology. The most recent analysis estimates that nanoscience will produce $2.6 trillion in economic output by 2015.[14]

The U.S. is currently the global leader in nanotechnology. The National Nanotechnology Initiative coordinates over $1 billion in annual federal research and grants. Total U.S. public and private spending on nanotechnology research and development totals about $3 billion annually, or one-third of the estimated $9 billion that is spent worldwide.[15]

Global competition in nanotechnology is fierce, and many countries are challenging the U.S.'s supremacy, specifically in the European Union and Asia. The EU is strengthening its research and development capabilities by promoting partnerships among companies and universities through its Nanosciences/Nanotechnology Action Plan for Europe. The Chinese government has implemented initiatives that employ over twice as many engineers as are working in nanotechnology in the U.S.[16] Thus, U.S. government-sponsored research is still vital if America is to remain a global leader in the national security applications of nanotechnology.

Toward the Future

Congress and the Administration have done much to encourage the development of nanoscience. The challenge is to maintain this momentum, facilitating commercial innovation and the application of new advances for national security purposes. A few key initiatives would bolster America's global leadership in the science of small things.

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13. "OIDA's Huff Discusses Nanophotonics in Keynote Address at NGC2007," *Business Wire*, March 16, 2007, at *www.allbusiness.com/services/business-services/4305830-1.html* (September 13, 2007).
14. Murdock, prepared statement, p. 41.
15. U.S. Department of State, Bureau of International Information Programs, "United States Leads Globe in Nanotechnology Research, Report Says," May 23, 2005, p. 1, at *http://usinfo.state.gov/xarchives/display.html?p=washfile-english&y=2005&m=May&x=20050523152217lcnirellep0.8238794* (September 14, 2007).
16. Jim O'Conner, "Motorola Trailblazing the Nanotechnology Frontier," testimony before the Subcommittee on Research, Committee on Science, U.S. House of Representatives, June 29, 2005, at *http://gop.science.house.gov/hearings/research05/june29/oconnor.pdf* (September 14, 2007).

Smarter Funding. In the near term, government research and development funds will continue to play a critical role in jump-starting national security innovations in nanotechnology. Congress should continue to provide strong support for nanoscience research programs in the Department of Defense and other federal agencies that support national security purposes.

Big Industry is currently averse to risk and is not providing the innovations needed for national security. In fact, investments in the private sector have been concentrated in just a few mature nanotech companies. In the first quarter of 2005, almost all of the venture capital invested in the nanotech industry went to four companies: NanoTex ($33 millon), Nanomix ($17 million), Nantero ($17 million), and NanoOpto ($12 million).[17]

The NNI needs to focus grants on the companies willing to pursue national security research. In doing so, however, it must walk a fine line between fostering cutting-edge technology advances and establishing a form of corporate welfare. Funding of the private sector should be limited to projects with such prohibitive risk and entry costs that companies would otherwise be unable to pursue them on their own.

Interagency Coordination. The DOD recently cited maintaining a consistent vision and stable funding as critical to future nanotechnology research and development.[18] Although federal agencies continue to coordinate through the NNI, each agency retains full control of its own budget decisions and sets its own research priorities.

The National Academy of Sciences has concluded that the "NNI is successfully establishing R&D programs with wider impact than could have been expected from separate agency funding without coordination." Increased coordination within the NNI would produce a centralized list of priorities and leverage resources even more effectively.[19]

Reform of Visa Issuance and Management. Congress needs to promote policies that continue to bring the best and the brightest in nanotechnology to study and work in the United States. Current visa policies are making it increasingly difficult to recruit students and scientists and to hold scientific conferences in the United States.

The nation's security and competitiveness relies heavily on people's ability to travel to the United States, but the current visa system is unnecessarily challenging, depriving the United States of many of the world's best and brightest scientists, students, and entrepreneurs. Long wait times for personal interviews are among the most frequently cited factors that make travel to the United States difficult.

Congress should end the requirement for a personal interview with virtually every non-immigration visa applicant and restore the Secretary of State's ability to waive personal interview requirements. The U.S. should also establish electronic visa applications to largely eliminate the cost of traveling to consulates and should reduce processing times to 30 days or less. All of these reforms could be implemented in a manner that makes international travel both more convenient and more secure.[20]

Safety and Environmental Issues. Congress should consider promoting the application of nanotechnologies for national security purposes in a manner similar to the provisions of the SAFETY Act, which facilitates the adoption of new capabilities for homeland security purposes.[21] Unlike in other industries such as biotechnology, there is no legal framework to guide responsibility and liability in nanotechnology.

17. Murdock, prepared statement, p. 48.
18. U.S. Department of Defense, "Defense Nanotechnology Research and Development Program," April 27, 2007, at *www.fas.org/irp/agency/dod/nano2007.pdf* (August 3, 2007).
19. National Research Council, Committee to Review the National Nanotechnology Initiative, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative* (Washington, D.C.: National Academies Press, 2006), p. 6, at *http://books.nap.edu/openbook.php?record_id=11752&page=6* (September 12, 2007).
20. James Jay Carafano, Brian C. Goebel, and Josh Kussman, "Coming to America: Initiatives for Better, Faster, and More Secure Visas," Heritage Foundation *Backgrounder* No. 1976, September 29, 2006, at *www.heritage.org/Research/NationalSecurity/bg1976.cfm*.

While nanotechnology has advanced rapidly in many fields, health and safety issues have lagged behind. Among the many concerns with nanotechnology are the possible toxicity of nanoparticles and their potential to self-replicate.[22] These hazards are not only public safety concerns, but also risks that are driving away many potential investors and companies.

Congress should establish clear legal guidelines for responsibility and liability in nanotechnology research and development with respect to national security requirements.

Conclusion

Nanotechnology promises to revolutionize many fields and industries and to increase military operational capabilities. Congress and the Administration should not only be aware of this growing field, but also ensure that the private sector—which is rightly making the largest investment in basic research and product development—remains competitive. Congress could take steps now to make this happen.

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21. In 2002, Congress enacted the Support Anti-Terrorism by Fostering Effective Technologies (SAFETY) Act to encourage companies to continue researching and developing biotechnologies vital to homeland security by protecting companies from litigation if their products fail during a terrorist attack or are harmfully employed by terrorists. The DHS has shown some success in implementing the legislation and granting SAFETY Act protections to goods and services that are employed to prevent or respond to terrorist threats. However, companies do not enjoy similar protections from other countries when the technologies are deployed outside the United States or adopted by U.S. friends and allies.
22. U.S. Department of Labor, Occupational Safety and Health Administration, National Advisory Committee on Occupational Safety and Health, "Minutes of December 8, 2004 Meeting," at *www.osha.gov/dop/nacosh/nagenda041204.html* (February 26, 2007).